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DESCRIPTION

MAGENTIC RECORDING MEDIUM AND MAGNETIC STORAGE DEVICE

Technical Field

The present invention relates to a magnetic recording medium, such as magnetic disk medium, and a magnetic storage device, such as magnetic disk device, provided with said magnetic recording medium.

Background Art

There has been a growing trend in recent years for magnetic disk devices to increase in capacity and recording density. The result is a continuing decrease in the size of recording bits formed on the magnetic recording medium. The currently available magnetic recording medium does not readily realize the ultra-high recording density exceeding 3 Gbit/in^2 without further reduction in medium noise. Therefore, it is important to make finer crystals constituting the magnetic film. Unfortunately, resulting fine magnetic crystals have such an extremely small volume that they decrease in recording magnetization by the strong influence of thermal energy even at normal temperature. In actuality, information recorded on a low-noise medium with a density of 115 kFCI is attenuated by more than 10% after 96 hours, as reported by Y. Hosoe et al. (IEEE Trans. Magn., 33, pp. 3028-3030, September 1997)

USP 5,693,426 discloses a magnetic recording medium which

consists of an orientation control layer having the B2 (CsCl)

structure and a magnetic layer formed thereon directly or indi-

rectly with a Cr underlayer interposed between them.

Japanese Patent Laid-open No. 21543/1995 discloses a dual

underlayer consisting of a first one of Cr and a second one of CrMo

alloy. According to this disclosure, the first Cr underlayer is

formed directly on the substrate.

Summary of the Invention

A magnetic layer of hcp crystal structure formed on an under-

layer of bcc crystal structure having (11.0) orientation. As the

result, the axis of easy magnetization of the magnetic layer ori-

ents in the plane of the layer, and the magnetic layer takes on the

crystal structure in which a plurality of magnetic crystal grains

grow on a single crystal grain of the underlayer in such a way that

the axes of easy magnetization intersect one another at right

angles. The magnetic layer of crystal structure makes it difficult

to control the grain size of crystals constituting the magnetic

layer, and the resulting crystals have such an extremely small

particle diameter that they are easily influenced by thermal fluc-

tuation. The result is a decrease with time in read output. The

magnetic layer of crystal structure hardly permits Cr to segregate

at grain boundaries, which results in a strong mutual interaction

between crystal grains constituting the magnetic layer. This in

turn leads to a decrease in effective anisotropy energy and coercive force.   This phenomenon is conspicuous particularly in the region of the magnetic layer where magnetization is small, and it poses a serious problem if the product of residual magnetic flux and magnetic layer thickness is smaller than 70 G·μm.

The magnetic layer should be free of crystal structure if it is to have good resistance to thermal fluctuation.   One way to achieve this objective is by the (211) orientation of the Cr underlayer or the like which adjoins the magnetic layer and has the bcc structure.   However, this is not practicable, because the Cr underlayer of bcc structure formed directly on the substrate by sputtering grows keeping the (110) plane (which is a closed packed plane) parallel to the substrate.   The (100) orientation (which is a matastable plane) is achieved if the substrate temperature is raised so that particles adhering to the substrate are activated during sputtering.   The (211) orientation needs such a higher particle energy that it hardly takes place preferentially.

The process in the above-cited USP 5,693,426 employs epitaxial growth to make the Cr underlayer having (211) orientation. To be more specific, the desired orientation is achieved by forming an orientation control layer (such as NiAl having the B2 crystal structure) on the substrate and growing the Cr underlayer thereon by epitaxial growth.   The effect of this layer structure is appar-

ent as shown in Fig. 2. It is to be noted that the B2 orientation control layer, the Cr underlayer, and the magnetic layer are almost identical in the lattice spacing of their two-dimensional lattice. This lattice matching is important for the underlayer and the magnetic layer to have (211) orientation and (10.0) orientation, respectively.

As shown in Fig. 2, the B2 crystal structure of the orientation control layer is similar to the bcc structure, but the former differs from the latter in that the atom at the center of the body is different from the atoms at the corners of the cube. When formed by thin-film technology, the orientation control layer of B2 crystal structure varies in orientation depending on particle energy. If particle energy is low, (110) orientation appears, which is most stable as in the case of bcc crystal structure. By contrast, if particle energy is high, the (100) orientation does not take place unlike the bcc crystal structure but the (211) orientation takes place.

A probable reason for this is as follows. For a material of B2 crystal structure having (100) orientation, it is necessary that the first layer be composed of Ni atoms only and the second layer be composed of Al atoms only. This does not happen, however, in such a state that Ni and Al atoms reach the substrate all together. Therefore, the (100) orientation hardly takes place. In the case

of the (110) and (211) orientations, the two-dimensional lattice in each plane consists of unit cells (two-dimensional unit cells) in which the ratio of Ni atoms to Al atoms is 1:1. This ratio agrees with the target composition. Therefore, orientation control layer of B2 crystal structure has (110) orientation (the most stable plane) when particle energy is low; on the other hand, orientation control layer with B2 crystal structure has (211) orientaion (the second most stable plane) when particle energy is high.

For reasons mentioned above, the magnetic disk medium disclosed in USP 5,693,426 is characterized by the magnetic layer which is composed of crystal grains of uni-crystalline-structure and hence has improved resistance to thermal fluctuation. Unfortunately, the magnetic layer of hcp crystal structure is composed of crystal grains whose c axis (the axis of easy magnetization) does not readily orient longitudinally. This leads to a low coercive force and a low resolution at the time of recording and reading. In addition, the underlayer has a large grain size, which makes the magnetic layer to have a large grain size. The large magnetic grain size increases media noise.

The present invention was completed to address the above-mentioned problems. It is a first object of the present invention to provide a low-noise longitudinal magnetic recording medium superior in resistance to thermal fluctuation. It is a second

object of the present invention to provide a magnetic storage

device having a recording density exceeding 3 Gbit/in^2.

The above-mentioned objects are achieved when the magnetic

layer is of uni-crystalline-structure and the magnetic layer is

composed of fine crystal grains.

The present invention is directed to a magnetic recording

medium which comprises a substrate, an orientation control layer

formed thereon, and a Co alloy magnetic layer formed thereon di-

rectly or indirectly with a Cr underlayer or Cr alloy underlayer

interposed between them, said orientation control layer containing

at least Ti in an amount not less than 35 at.% and not more than 65

at.% and Al in an amount not less than 35 at.% and not more than 65

at.%. According to a preferred embodiment, the above-mentioned

orientation control layer substantially has the L10-type (AuCu I-

type) crystal structure, so that the axis of easy magnetization

orients longitudinally in the magnetic layer. The L10-type crystal

structure resembles the fcc crystal structure except that the atom

at the center of the side face differs from other atoms. Examples

of the material having the L10 crystal structure include TiAl, NiZn,

AuCu, FePd, and NiMn. TiAl is practicable judging from its phase

diagram.

The present invention is directed also to a magnetic re-

cording medium which comprises a substrate, an orientation control

layer formed thereon, and a Co alloy magnetic layer formed thereon with a Cr underlayer or Cr alloy underlayer interposed between them, said orientation control layer containing at least one element selected from group A (consisting of Ni and Co) in an amount of from 30 at.% to 60 at.%, Al in an amount from 20 at.% to 30 at.%, and one element selected from group B (consisting of Ti and Zr) in an amount from 20 at.% to 30 at.%. According to a preferred embodiment, the above-mentioned orientation control layer substantially has the L21-type (Cu$_2$AlMn type) crystal structure, so that the axis of easy magnetization orients longitudinally in the magnetic layer. Like the B2 crystal structure, the L21 crystal structure consists of four cubes each characterized in that the atom at the center of the body differs from the atoms at the corners of the body. But unlike the B2 crystal structure, the L21 crystal structure has two kinds of body center atoms, so that adjoining cubes have different atoms at the body center. Examples of the material having the L21 crystal structure include Ni$_2$AlTi, Ni$_2$AlZr, Co$_2$AlTi, and Co$_2$AlZr.

The present invention is directed also to a magnetic recording medium which comprises a substrate, an orientation control layer formed thereon, and a Co alloy magnetic layer formed thereon with a Cr underlayer or Cr alloy underlayer interposed between them, said orientation control layer containing at least one species of

element selected from Al, Cu, Rh, Pd, Ag, Ir, Pt, and Au in an

amount not less than 70 at.%. According to a preferred embodiment,

the above-mentioned orientation control layer substantially has the

fcc crystal structure, so that the axis of easy magnetization

orients longitudinally in the magnetic layer.

The present invention is directed also to a magnetic re-

cording medium which comprises a substrate, an orientation control

layer formed thereon, and a Co alloy magnetic layer formed thereon

with a Cr underlayer or Cr alloy underlayer interposed between them,

said orientation control layer having the B2 (CsCl) crystal struc-

ture incorporated with at least B. According to a preferred em-

bodiment, the amount of B to be added to the above-mentioned orien-

tation control layer is not less than 0.05 at.% and not more than

15 at.%. The amount of B (not less than 0.05 at.% and not more

than 15 at.%) is determined on the basis of the material having the

B2-type crystal structure. The thus added B precipitates out at

the grain boundary in the orientation control layer, thereby making

crystal grains fine. In the case where the amount of B is compara-

tively large, B in the grain boundary exists together with metallic

atoms contained in the orientation control layer having the B2

crystal structure. Such a region is amorphous and substantially

crystalline grains decrease in particle diameter. So long as the

crystalline portion in the orientation control layer retains sub-

stantially the B2 crystal structure, the (211) orientation of Cr or Cr alloy takes place as intended. In order that the crystalline portion retains the B2 crystal structure, it is necessary that the amount of B to be added should not exceed 15 at.%. In case of an excess amount, the axis of easy magnetization has a weak tendency toward longitudinal orientation in the magnetic layer. With an amount less than 0.05 at.%, B does not produce the effect of making crystal grains fine. The crystalline portion in the orientation control layer having the B2 (CsCl) structure should be composed of at least one kind of alloy selected from Al-Co, Al-Fe, Al-Ni, Al-Pd, Co-Ga, Co-Fe, Co-Ti, Cu-Pd, Cu-Zn, Ga-Ni, Ga-Rh, and Ru-Si. This is desirable for the (211) orientation to take place in the Cr underlayer or Cr alloy underlayer which is formed on the orientation control layer.

It was confirmed that X-ray diffraction by θ-2θ scan method detects in the magnetic layer the (10.0) plane parallel to the substrate but does not detect in the magnetic layer the (11.0) plane parallel to the substrate. (There is an instance in which the magnetic layer has a small number of (00.2) and (10.1) planes.) The foregoing suggests that the orientation control layer interposed between the substrate and the underlayer changes not only the plane of preferred orientation in the underlayer but also the fine structure in the magnetic layer.

The above-mentioned magnetic layer should preferably contain Cr in an amount not less than 15 at.% and not more than 25 at.% and Pt in an amount not less than 4 at.% and not more than 25 at.%, so that the recording medium has a high coercive force and a low noise level. The magnetic layer may be incorporated with Ta, Ti, and Nb for further noise reduction. In this case the total amount of these elements should not exceed 8 at.% so that the magnetic layer will not become non-magnetic. Of the components constituting the magnetic layer, Co should account for not less than 62 at.%. Otherwise, the residual magnetic flux density remarkably decreases and the magnetic flux leaking from the recording medium decreases, making it difficult for the magnetic head to read signals.

Epitaxial growth of the magnetic layer of hcp structure on the underlayer of bcc structure causes crystals of different structure to grow forcibly. Therefore, it gives defects or forms fine magnetic crystal grains in the initial stage of crystal growth in the magnetic layer. Such defects and fine crystal grains are readily subject to thermal fluctuation and hence they cause the read output to decrease with time at a faster rate after signal recording. In order to minimize such adverse effects, it is desirable to interpose a non-magnetic interlayer of hcp structure between the underlayer and the magnetic layer. This interlayer absorbs defects and fine particles that occur at the interface with

the underlayer of bcc structure and hence it protects the magnetic layer from adverse effects. The non-magnetic interlayer of hcp structure should preferably be formed from a Co-based material containing at least Cr in an amount not less than 25 at.%.

The present invention is directed also to a magnetic storage device having a magnetic recording medium, a driver to turn said magnetic recording medium in the recording direction, a magnetic head consisting of a recording element and a read-back element, a means to move said magnetic head relative to said magnetic recording medium, and a record-read signal processing means to perform waveform processing on input signals to and output signals from said magnetic head, wherein said magnetic recording medium is any one of the magnetic recording media mentioned above and the read-back element of said magnetic head is that of magnetoresistive effect type. The magnetic storage device has a recording density more than 3 Gbit/in^2.

Brief Description of the Drawings

Fig. 1 is a diagram showing the model of the crystal structure of the orientation control layer having the L10-type crystal structure according to the present invention.

Fig. 2 is a diagram showing the epitaxial relation in the magnetic recording medium having the orientation control layer of B2-type crystal structure.

Fig. 3 is a schematic sectional view showing the magnetic recording medium in one example of the present invention.

Fig. 4 is a schematic diagram showing the structure of the magnetic head provided with an element that utilizes the magnetoresistive effect.

Fig. 5 is a diagram showing the structure of the magnetoresistive sensor.

Fig. 6 is a diagram showing the structure of the magnetoresistive sensor of spin valve type.

Fig. 7 is a schematic diagram showing the magnetic storage device.

Fig. 8 is a diagram showing the magnetic properties and media noise in Example 1 compared with those in Comparative Example 1.

Fig. 9 is a diagram showing the diffraction intensity of the (10.0) plane of the magnetic layer in Example 1 compared with that in Comparative Example 1.

Fig. 10 is a diagram showing the magnetic properties and media noise in Example 2 compared with those in Comparative Example 2.

Fig. 11 is a diagram showing the diffraction intensity of the (10.0) plane of the magnetic layer in Example 2 compared with that in Comparative Example 2.

Fig. 12 is a diagram showing the model of the crystal struc-

ture of the orientation control layer having the L21-type crystal structure according to the present invention.

Fig. 13 is a diagram showing the magnetic properties and media noise in Example 3 compared with those in Comparative Example 3.

Fig. 14 is a diagram showing the diffraction intensity of the (10.0) plane of the magnetic layer in Example 3 compared with that in Comparative Example 3.

Fig. 15 is a diagram showing the model of the crystal struc- ture of the orientation control layer having the fcc-type crystal structure according to the present invention.

Fig. 16 is a diagram showing the magnetic properties and media noise in Example 4 compared with those in Comparative Example 4.

Fig. 17 is a diagram showing the diffraction intensity of the (10.0) plane of the magnetic layer in Example 4 compared with that in Comparative Example 4.

Fig. 18 is a diagram showing how media noise varies depending on the B content in the magnetic recording medium according to the present invention.

Detailed Description

~~Best Mode for Carrying out the Invention.~~

The invention will be described in more detail with reference to the following examples.

Example 1

This example demonstrates a magnetic disk of the present invention which is shown in section in Fig. 3. This magnetic disk was produced in the following manner.

A glass substrate 30 (65 mm in outside diameter) was covered with an orientation control layer 31 (and 31') of Ti-50at.% Al (100 nm thick) by DC magnetron sputtering under the condition that the substrate temperature is 270°C, the Ar gas pressure is 2.0 mTorr, and the input power density is 0.7 W/cm^2. On the orientation control layer were sequentially formed a first underlayer 32 (and 32') of Cr (20 nm thick), a second underlayer 33 (and 33') of Cr-30at.% Mo (20 nm thick), a magnetic layer 34 (and 34') of Co-20at.% Cr-12at.% Pt-1.5at.% Ti (20 nm thick), and a protective layer 35 (and 35') of C (5 nm thick) under the same condition as mentioned above. The number preceding each element represents the content of the relevant element.

In Comparative Example 1, a magnetic disk was prepared in the same way as in Example 1 except that the orientation control layer 31 (and 31') of Ti-50at.% Al was replaced by that of Ni-50at.% Al. The orientation control layer in Example 1 had the L10 crystal structure, whereas that in Comparative Example 1 had the B2 crystal structure.

Fig. 8 shows the in-plane magnetic properties and media noise

in Example 1 and Comparative Example 1. The value of media noise

is that which was measured for signals recorded at 250 kFCI. The

value in Example 1 is unity and the value in Comparative Example 1

is relative to unity. It is noted that the magnetic disk in Exam-

ple 1 is higher in coercive force (H_c) and lower in media noise

than that in Comparative Example 1. It is also noted that the

magnetic disk in Example 1 is higher in coercivity squareness (S*)

than that in Comparative Example 1. This suggests a better resolu-

tion.

The CoCrPt magnetic layer was tested for diffraction inten-

sity at the (10.0) plane by X-ray diffraction. The results are

shown in Fig. 9. The value in Example 1 is unity and the value in

Comparative Example 1 is relative to unity. The larger the value,

the more the axis of easy magnetization orients in the plane of the

magnetic layer. It is understood that the diffraction intensity is

higher and there are more magnetic particles whose axis of easy

magnetization orients in the plane in Example 1 than in Comparative

Example 1.

The CoCrPt magnetic layer of the magnetic disk in both Exam-

ple 1 and Comparative Example 1 does not give diffraction due to

the (11.0) plane. This suggests that the crystal grains in the

magnetic layer has the uni-crystalline-structure.

Incorporation of 10at.% B into the orientation control layer

of the magnetic disk in Example 1 reduced media noise by 10%. A probable reason for this is that B in the orientation control layer segregates in grain boundaries, thereby making crystal grains fine.

Examples of materials having the L10 crystal structure include TiAl, NiZn, AuCu, FePd, and NiMn. Of these examples, TiAl is practical judging from its phase diagram.

In this example, the orientation control layer of L10 structure must cause the Cr underlayer formed thereon to have the (211) orientation. To this end, it is necessary that the (101) and (011) oriented orientation control layer, as shown in Fig. 1. Since the L10 structure is tetragonal, (110) is not equivalent to (101) and (011). The (110) orientation gives the two dimensional lattice structure in which each layer consists of identical atoms or the first layer consists only of Ti atoms and the second layer consists only of Al atoms. Such orientation, however, hardly occurs under the condition that Ti atoms and Al atoms reach the substrate all together. On the other hand, in the case of the (101) or (011) orientation, the ratio of atoms constituting the two dimensional lattice agrees with the ratio of atoms constituting the unit cell and the target composition. Such orientation easily occurs as desired.

The lattice spacing of the two-dimensional lattice resulting from the orientation control layer of L10 structure which has (101)

or (011) orientation is almost identical with that resulting from

the (211) oriented Cr underlayer and the (10.0) oriented magnetic

layer. Therefore, the Cr underlayer epitaxially grows with hav-

ing(211) orientation and the magnetic layer epitaxially grows with

having the (10.0) orientation. For this reason, the crystal grains

of the magnetic layer are of uni-crystalline-structure and the

recording medium thus obtained has good resistance to thermal

fluctuation.

The orientation control layer of L10 crystal structure should

preferably contain Ti and Al in an atomic ratio of 1:1. The pre-

ferred layer composition is such that the content of Ti is not less

than 35 at.% and not more than 65 at.% and the content of Al is not

less than 35 at.% and not more than 65 at.%. The orientation

control layer of L10 structure which is actually obtained by sput-

tering has a composition which is slightly different from the

target composition. Thus the L10 crystal structure will have some

defects and disorders. However, this is not a serious problem.

As mentioned above, the orientation control layer is formed

from a material of L10 crystal structure, such as TiAl, NiZn, AuCu,

FePd, and NiMn. These materials may be incorporated with any other

element in an amount not more than 30 at.%, such that the added

element precipitates out in the grain boundaries. This is one way

to make fine the crystal grains of L10 structure. Since precipita-

tion of the added element in the grain boundaries forms an amor-phous region, the crystal grains of L10 structure do not prevent Cr from the (211) orientation. Incorporation with B is particularly effective, because B easily segregates in the grain boundaries, thereby making fine crystal grains in the orientation control layer. The result is that the magnetic layer formed on the orientation control layer is composed of fine crystal grains, which contributes to noise reduction. The kind of the added element is not specifi-cally restricted so long as the crystal grains in the orientation control layer retain the L10 structure so that the desired effect is produced. In order that the crystal grains retain the L10 structure, it is necessary that the amount of the added element be not more than 30 at.% of the total composition of the orientation control layer.

In this example, the orientation control layer is composed of the crystal gains of L10 structure which contains a large amount of Ti. Ti makes the crystal grains fine. The result is that the magnetic layer formed on the orientation control layer is composed of fine crystal grains and hence the resulting magnetic disk has a low noise level.

In this example, a mention was made of the magnetic disk in which the Cr underlayer is interposed between the magnetic layer and the orientation control layer of L10 structure. However, the

construction of the magnetic disk may be modified such that the magnetic layer is formed directly on the orientation control layer of L10 structure. This poses no problem in view of the fact that the two-dimensional lattice of the magnetic layer and the two-dimensional lattice of the orientation control layer of L10 structure have almost the same lattice spacing, as shown in Fig. 1. However, in the case where the Cr underlayer is not formed, the axis of easy magnetization has a slightly weak tendency toward in-plane orientation in the magnetic layer. This leads to a decrease in coercive force and an increase in noise level.

For the magnetic recording medium to have a high coercive force and a low noise level, it is common practice to incorporate the magnetic layer with such an element as Pt, Ta, Ti, and Nb. Incorporation with such an element causes the magnetic layer of hcp structure to have a larger lattice constant and the two-dimension lattice formed by the (10.0) plane of the magnetic layer has a larger lattice spacing. The result is poor lattice matching between the magnetic layer and the orientation control layer of L10 structure and poor lattice matching between the magnetic layer and the Cr underlayer. Therefore, the underlayer should be made of an alloy having a large lattice constant. Such an alloy is exemplified by those of Cr-Ti (5-50 at.%), Cr-Mo (5-100 at.%), and Cr-Mo-Ti. The underlayer made of any of these alloys improves the in-

plane orientation of the axis of easy orientation of the magnetic layer. It is important that the underlayer have the bcc crystal structure. The Cr-Mo alloy used for the alloy underlayer is a homogeneous solid solution as indicated by its phase diagram for bulk metal and hence it has always the bcc crystal structure. This property makes it easy to produce crystals having any desired lattice spacing. The Cr-Ti alloy gives an underlayer consisting of fine crystal grains and hence the magnetic layer formed thereon also consists of fine crystal grains. This is desirable for noise reduction. However, the Cr-Ti alloy for the underlayer should contain a limited amount of Ti not exceeding 50 at.% because Ti has the hcp crystal structure. The underlayer made of Cr-Mo-Ti alloy has the property derived from respective properties of Cr-Mo alloy and Cr-Ti alloy in proportion to the content of each element. The alloy for the underlayer may contain any of Nb, Ta, and W in place of Cr, Mo, and Ti (although the resulting alloy is slightly inferior to the alloy containing Cr, Mo, and Ti). Other elements than mentioned above should not be used because they disturb crystal orientation and give rise to large crystal grains, which leads to a decrease in coercive force and an increase in noise.

According to a preferred embodiment, the underlayer is of double-layer structure, with the first layer containing Cr and the second layer which is formed on the first underlayer containing at

least one element selected from Cr, Nb, Mo, Ta, W, and Ti. This underlayer is desirable because it permits the axis of easy magnetization to assume in-plane orientation in the magnetic layer. The results of the present inventors' experiments indicate the following. If the Cr alloy underlayer is formed directly on the orientation control layer of L10 structure, lattice matching between them is poor and hence the crystal orientation in the underlayer as well as the magnetic layer is poor, because the two-dimensional lattice of the former has a much larger lattice spacing than that of the latter. This problem was solved by replacing the underlayer with that of double-layer structure which consists of a first layer of Cr (adjacent to the orientation control layer of L10 structure) and a second layer which has a larger lattice constant than Cr.

The magnetic recording medium in Example 1 exhibits its full performance when it works together with a magnetic head provided with a sensor (for read only) that utilizes the magnetoresistive effect. An example of the magnetic head is shown in Fig. 4.

The magnetic head consists of a write head and a read head. The write head is that of thin-film induction type consisting of a pair of recording magnetic poles 40 and 41 and a coil 42. The read head is a magnetoresistive head consisting of a magnetic pole 41 (which functions also as a magnetic shield for the read head), a

magnetic shield layer 45 facing the magnetic pole 41, a magnetore-

sistive sensor 43, and a conductor layer 44 (which functions as an

electrode). There is a 0.3-μm gap layer between the recording

magnetic poles. Both the magnetic pole 41 and the magnetic shield

45 are 1 μm thick, and the gap between them is 0.25 μm. The mag-

netic head is mounted on the magnetic head slider base 46. Inci-

dentally, there are not shown in Fig. 4 the gap layer between the

shield layer and the magnetoresistive sensor and the gap layer

between the recording magnetic poles.

Fig. 5 is an enlarged sectional view showing the structure of

the magnetoresistive sensor 43 in detail. There is shown a signal

sensing region 50, which has sloped parts 55. The magnetoresistive

sensor 43 consists of a gap layer of aluminum oxide, a transverse

bias layer 52, a separating layer 53, and a magnetoresistive ferro-

magnetic layer 54, which are sequentially formed on top of the

other. The magnetoresistive ferromagnetic layer 54 is an NiFe

alloy (20 nm thick). The NiFe alloy may be replaced with a ferro-

magnetic alloy, such as NiFeRh, which has a comparatively high

electrical resistance and good soft magnetic properties. The

transverse bias layer 52 is magnetized by the magnetic field pro-

duced by the sense current flowing through the magnetoresistive

ferromagnetic layer 54. Magnetization takes place in the in-plane

direction (longitudinal direction) perpendicular to the sense

current. Thus the transverse bias layer 52 applies a bias magnetic

field to the magnetoresistive ferromagnetic layer 54 in the trans-

verse direction. In this way the magnetoresistive sensor produces

a read output which is linear for the leakage flux from the mag-

netic disk. The separating layer 53 prevents the sense current

from the magnetoresistive ferromagnetic layer 54 from shunting. It

is made of Ta having a comparatively high electrical resistance,

and it is 5 nm thick. The sloped part 55 of the magnetoresistive

sensor 43 is covered with a permanent magnet layer 56 and an elec-

trode 57. The former makes the magnetoresistive ferromagnetic

layer 54 a single domain, and the latter leads out signals. The

permanent magnetic layer 56 should have a high coercive force and

invariably keep its direction of magnetization. It is made of CoCr

alloy or CoCrPt alloy. For a larger output, the magnetoresistive

sensor 43 should preferably be that of spin valve type as shown in

Fig. 6. It consists of a signal sensing region 60 and sloped parts

67, which are of laminate structure. The laminate consists of a

gap layer 61 of aluminum oxide, a Ta buffer layer 62 (5 nm thick),

a first magnetic layer 63 (7 nm thick), a Cu intermediate layer 64

(1.5 nm thick), a second magnetic layer 65 (3 nm thick), and an

antiferromagnetic layer 66 of Fe-50at.% Mn alloy (10 nm thick),

which are formed on top of the other. The first magnetic layer 63

is made of Ni-20at.% Fe alloy and the second magnetic layer 65 is

made of Co. The second magnetic layer 65 is magnetized in one
fixed direction by the exchange field from the antiferromagnetic
alloy layer 66. By contrast, the first magnetic layer 63 (which is
in contact with the second magnetic layer 65 with a non-magnetic
interlayer 64 interposed between them) varies in the direction of
magnetization depending on the leakage field from the magnetic
recording medium. As the two magnetic layers magnetize in differ-
ent directions, the three layers (the first magnetic layer 63, the
intermediate layer 64, and the second magnetic layer 65) as a whole
changes in resistance. This phenomenon is called spin valve effect.
Incidentally, as in the ordinary magnetoresistive sensor shown in
Fig. 5, a permanent magnet layer 68 and an electrode 69 to lead out
signals are formed on the sloped part 67. The magnetic head in
this example is that of spin valve type which has the magnetoresis-
tive sensor43 utilizing the spin valve effect as shown in Fig. 6.

Fig. 7 shows a magnetic storage device consisting of the
magnetic disk and magnetic head demonstrated in this example. Fig.
7(a) is a top view and Fig. 7(b) is a schematic sectional view
taken in the direction of the arrows along the line A-A'.

There is shown a magnetic disk 70, which is a longitudinal
magnetic recording medium. A plurality of magnetic disks are
supported on a shaft connected to a disk driver 71. Each face of
the magnetic disk is swept by the magnetic head 72 which is shown

in Fig. 4. The magnetic head 72 is moved to a desired track by the magnetic head driver 73 in such a way that the flying height is not more than 0.05 μm and the head positioning accuracy is not more than 0.5 μm. The magnetic head 72 reproduces signals, which subsequently undergo waveform processing by the reproduced signal processing unit 74. The reproduced signal processing unit 74 consists of an amplifier, analog equalizer, AD converter, digital equalizer, and maximum likelihood decoder. The analog equalizer fixes and restores the reproduced waveforms. (In reproduction by the magnetic head that utilizes the magnetoresistive effect, reproduced waveforms may be asymmetrical for positive and negative values on account of the characteristic properties of the magnetic head or different from those of recorded signals on account of the frequency characteristics of the write-read system. Such waveforms lead to erratic signal reading.) The restored waveforms are further fixed by the AD converter for digital conversion and the digital equalizer. The signals restored in this manner are finally decoded by the maximum likelihood decoder. The reproduced signal processing unit constructed as mentioned above writes and reads signals at an extremely low error rate. Incidentally, the equalizer and maximum likelihood decoder may be any existing ones.

Owing to the above-mentioned construction, the magnetic storage device in this example has a recording density exceeding 3

Gbit/in^2. The recording density is three times higher than that of the conventional magnetic storage device. The magnetic storage device keeps more than twice the recording density of the conventional magnetic storage device even when the maximum likelihood decoder in the recording-reproducing signal processing unit is replaced with an existing waveform discriminator.

What is mentioned above in this example is about the magnetic disk medium and the magnetic storage device provided with it. Needless to say, the present invention can be applied to magnetic recording media in any form (such as tape and card having a magnetic layer on one side) and a magnetic storage device provided with such a magnetic recording medium.

No specific restrictions are imposed on the method of producing the magnetic disk media. The above-mentioned DC magnetron sputtering may be replaced with any of ECR sputtering, ion beam sputtering, vacuum deposition, plasma CVD, coating, plating, etc.

Example 2

This example demonstrates another magnetic disk whose construction and manufacturing process are explained in the following.

As in Example 1 shown in Fig. 3, a glass substrate 30 (65 mm in outside diameter) was covered with an orientation control layer 31 (and 31') of Ni-25at.% Al-25at.% Ti (100 nm thick) by DC magnetron sputtering under the condition that the substrate temperature

is 270°C, the Ar gas pressure is 2.0 mTorr, and the input power

density is 0.7 W/cm^2. On the orientation control layer were se-

quentially formed a first underlayer 32 (and 32') of Cr (20 nm

thick), a second underlayer 33 (and 33') of Cr-30at.% Mo (20 nm

thick), a magnetic layer 34 (and 34') of Co-20at.% Cr-12at.% Pt-

1.5at.% Ti (20 nm thick), and a protective layer 35 (and 35') of C

(5 nm thick) under the same condition as mentioned above. The

number preceding each element represents the content of the rele-

vant element.

In Comparative Example 2, a magnetic disk was prepared in the

same way as in Example 2 except that the orientation control layer

31 (and 31') of Ni-25at.% Al-25at.% Ti was replaced by that of Ni-

50at.% Al. The orientation control layer in Example 2 had the L21

crystal structure, whereas that in Comparative Example 2 had the B2

crystal structure.

Fig. 10 shows the in-plane magnetic properties and media

noise in Example 2 and Comparative Example 2. The value of media

noise is that which was measured for signals recorded at 250 kFCI.

The value in Example 2 is unity and the value in Comparative Exam-

ple 2 is relative to unity. It is noted that the magnetic disk in

Example 2 is higher in coercive force (H_c) and lower in media noise

than that in Comparative Example 2. It is also noted that the

magnetic disk in Example 2 is higher in coercivity squareness (S*)

than that in Comparative Example 2. This suggests a better resolu-
tion.

The CoCrPt magnetic layer was tested for diffraction inten-
sity at the (10.0) plane by X-ray diffraction. The results are
shown in Fig. 11. The value in Example 2 is unity and the value in
Comparative Example 2 is relative to unity. The larger the value,
the more the axis of easy magnetization orients in the plane of the
magnetic layer. It is understood that the diffraction intensity is
higher and there are more magnetic particles whose axis of easy
magnetization orients in the plane in Example 2 than in Comparative
Example 2.

The CoCrPt magnetic layer of the magnetic disk in both Exam-
ple 2 and Comparative Example 2 does not give diffraction due to
the (11.0) plane. This suggests that the crystal grains in the
magnetic layer has the uni-crystalline-structure.

Experiments with the orientation control layer 31 (and 31')
in which the alloy was replaced with Ni-25at.% Al-25at.% Zr, Co-25%
Al-25at.% Ti, or Co-25at.% Al-25at.% Zr gave better results than in
Comparative Example 2. It was found that the magnetic recording
medium in which the orientation control layer contains Ti and has
the L21 structure is about 10% lower in media noise than that in
which the orientation control layer contains Zr and has the L21
structure. By contrast, it was also found that the magnetic re-

cording medium in which the orientation control layer contains Zr and has the L21 structure has 10-20% higher coercive force. In addition, incorporation of 10at.% B into the orientation control layer of the magnetic disk in Example 2 reduced media noise by 10%. A probable reason for this is that B in the orientation control layer segregates in grain boundaries, thereby making crystal grains fine.

Like the B2 crystal structure, the L21 crystal structure consists of four cubes each characterized in that the atom at the center of the body differs from the atoms at the corners of the body. But unlike the B2 crystal structure, the L21 crystal structure has two kinds of body center atoms, so that adjoining cubes have different atoms at the body center. Examples of the material having the L21 crystal structure include Ni_2AlTi, Ni_2AlZr, Co_2AlTi, and Co_2AlZr. The subscript number following the element symbol denotes the ratio of atoms contained in the unit cell. For example, Ni_2AlTi indicates that the unit cell consists of eight atoms of Ni and four atoms each of Al and Ti. Thus the ratio of atoms is Ni:Al:Ti = 2:1:1.

In this example, the orientation control layer of L21 structure must cause the Cr underlayer formed thereon to have the (211) orientation. To this end, it is necessary that the (211) oriented orientation control layer like the orientation control layer of B2

structure. As shown in Fig. 1, when the orientation control layer

of L21 structure has the (211) orientation, the ratio of atoms

constituting the two-dimensional lattice agrees with that of the

target composition and that of the unit cell. Thus, the (211)

orientation readily takes place as in the case of the orientation

control layer of B2 structure. When the orientation control layer

of L21 structure has the (211) orientation, the lattice spacing of

the two-dimensional lattice is almost equal to that of the Cr

underlayer (which has the (211) orientation as shown in Fig. 12)

and the magnetic layer which has the (10.0) orientation. Therefore,

the Cr underlayer epitaxially grows with having the (211) orienta-

tion and the magnetic layer epitaxially grows with having the

(10.0) orientation. The resulting magnetic layer consists of

crystal grains of uni-crystalline-structure, and this makes the

magnetic recording medium to have good resistance to thermal fluc-

tuation.

The orientation control layer of L21 crystal structure should

preferably contain Ni or Co, Al, and Ti or Zr in an atomic ratio of

2:1:1. The preferred layer composition is such that the content of

Ni or Co is 30 to 60 at.%, the content of Al is 20 to 30 at.%, and

the content of Ti or Zr is 20 to 30 at.%. The orientation control

layer actually obtained by sputtering has a composition which is

slightly different from the target composition. Thus the L21

crystal structure will have some defects and disorders. However,
this is not a serious problem.

The material having the L21 crystal structure may be incorporated
with any other element in an amount not more than 30 at.%, such
that the added element precipitates out in the grain boundaries.
This is one way to make fine the crystal grains. Since precipita-
tion of the added element in the grain boundaries forms an amor-
phous region, the crystal grains do not prevent Cr from the (211)
orientation. The kind of the added element is not specifically
restricted so long as the crystal grains in the orientation control
layer retain the L21 structure so that the desired effect is pro-
duced. In order that the crystal grains retain the L21 structure,
it is necessary that the amount of the added element be not more
than 30 at.% of the total composition of the orientation control
layer. Incorporation with B is particularly effective in noise
reduction, because B easily segregates in the grain boundaries,
thereby making fine crystal grains in the orientation control layer.

The above-mentioned material of L21 structure for the orientation
control layer contains either Ti or Zr. Ti or Zr makes the crystal
grains fine, which leads to the recording medium having a low noise
level. Ti is particularly effective in grain refinement and noise
reduction. By contrast, Zr is also effective in grain refinement
and noise reduction but is particularly effective in the (211)

orientation of Cr and in increasing the read output.

In this example, a mention was made of the magnetic disk in which the Cr underlayer is interposed between the magnetic layer and the orientation control layer of L21 structure. However, the construction of the magnetic disk may be modified such that the magnetic layer is formed directly on the orientation control layer of L21 structure. This poses no problem in view of the fact that the two-dimensional lattice of the magnetic layer and the two-dimensional lattice of the orientation control layer of L21 structure have almost the same lattice spacing, as shown in Fig. 12. However, in the case where the Cr underlayer is not formed, the axis of easy magnetization has a slightly weak tendency toward in-plane orientation in the magnetic layer. This leads to a decrease in coercive force and an increase in noise level.

For the magnetic recording medium to have a high coercive force and a low noise level, it is common practice to incorporate the magnetic layer with such an element as Pt, Ta, Ti, and Nb. Incorporation with such an element causes the magnetic layer of hcp structure to have a larger lattice constant and the two-dimension lattice formed by the (10.0) plane of the magnetic layer has a larger lattice spacing. (The lattice constant of Co is shown in Fig. 2.) The result is poor lattice matching between the magnetic layer and the orientation control layer of L21 structure and poor

lattice matching between the magnetic layer and the Cr underlayer.

Therefore, the underlayer should be made of an alloy having a large

lattice constant. Such an alloy is exemplified by those of Cr-Ti

(5-50 at.%), Cr-Mo (5-100 at.%), and Cr-Mo-Ti. The underlayer made

of any of these alloys improves the in-plane orientation of the

axis of easy orientation of the magnetic layer. It is important

that the underlayer have the bcc crystal structure. The Cr-Mo

alloy used for the alloy underlayer is a homogeneous solid solution

as indicated by its phase diagram for bulk metal and hence it has

always the bcc crystal structure. This property makes it easy to

produce crystals having any desired lattice spacing. The Cr-Ti

alloy gives an underlayer consisting of fine crystal grains and

hence the magnetic layer formed thereon also consists of fine

crystal grains. This is desirable for noise reduction. However,

the Cr-Ti alloy for the underlayer should contain a limited amount

of Ti not exceeding 50 at.% because Ti has the hcp crystal struc-

ture. The underlayer made of Cr-Mo-Ti alloy has the property

derived from respective properties of Cr-Mo alloy and Cr-Ti alloy

in proportion to the content of each element. The alloy for the

underlayer may contain any of Nb, Ta, and W in place of Cr, Mo, and

Ti (although the resulting alloy is slightly inferior to the alloy

containing Cr, Mo, and Ti). Other elements than mentioned above

should not be used because they disturb crystal orientation and

give rise to large crystal grains, which leads to a decrease in coercive force and an increase in noise.

According to a preferred embodiment, the underlayer is of double-layer structure, with the first layer containing Cr and the second layer which is formed on the first underlayer containing at least one element selected from Cr, Nb, Mo, Ta, W, and Ti. This underlayer is desirable because it permits the axis of easy magnetization to assume in-plane orientation in the magnetic layer. The results of the present inventors' experiments indicate the following. If the Cr alloy underlayer is formed directly on the orientation control layer of L21 structure, lattice matching between them is poor and hence the crystal orientation in the underlayer as well as the magnetic layer is poor, because the two-dimensional lattice of the former has a much larger lattice spacing than that of the latter. This problem was solved by replacing the underlayer with that of double-layer structure which consists of a first layer of Cr (adjacent to the orientation control layer of L21 structure) and a second layer which has a larger lattice constant than Cr.

The magnetic disk in this example is combined with the magnetic head shown in Fig. 6 to form the magnetic storage device as shown in Fig. 7. The magnetic head is that of spin valve type provided with a magnetoresistive sensor which utilizes the spin

valve effect.   Owing to the above-mentioned construction, the

magnetic storage device in this example has a recording density

exceeding 3 Gbit/in^2.   The recording density is three times higher

than that of the conventional magnetic storage device.   The mag-

netic storage device keeps more than twice the recording density of

the conventional magnetic storage device even when the maximum

likelihood decoder in the recording-reproducing signal processing

unit is replaced with an existing waveform discriminator.

Example 3

   This example demonstrates another magnetic disk whose con-

struction and manufacturing process are explained in the following.

   As in Example 1 shown in Fig. 3, a glass substrate 30 (65 mm

in outside diameter) was covered with an orientation control layer

31 (and 31') of Au (100 nm thick) by DC magnetron sputtering under

the condition that the substrate temperature is 270°C, the Ar gas

pressure is 2.0 mTorr, and the input power density is 0.7 W/cm^2.

On the orientation control layer were sequentially formed a first

underlayer 32 (and 32') of Cr (20 nm thick), a second underlayer 33

(and 33') of Cr-30at.% Mo (20 nm thick), a magnetic layer 34 (and

34') of Co-20at.% Cr-12at.% Pt-1.5at.% Ti (20 nm thick), and a

protective layer 35 (and 35') of C (5 nm thick) under the same

condition as mentioned above.   The number preceding each element

represents the content of the relevant element.

In Comparative Example 3, a magnetic disk was prepared in the same way as in Example 3 except that the orientation control layer 31 (and 31') of Au was replaced by that of Ni-50at.% Al. The orientation control layer in Example 3 had the fcc crystal structure, whereas that in Comparative Example 3 had the B2 crystal structure.

Fig. 13 shows the in-plane magnetic properties and media noise in Example 3 and Comparative Example 3. The value of media noise is that which was measured for signals recorded at 250 kFCI. The value in Example 3 is unity and the value in Comparative Example 3 is relative to unity. It is noted that the magnetic disk in Example 3 is higher in coercive force (H_c) and lower in media noise than that in Comparative Example 3. It is also noted that the magnetic disk in Example 3 is higher in coercivity squareness (S*) than that in Comparative Example 3. This suggests a better resolution.

The CoCrPt magnetic layer was tested for diffraction intensity at the (10.0) plane by X-ray diffraction. The results are shown in Fig. 14. The value in Example 3 is unity and the value in Comparative Example 3 is relative to unity. The larger the value, the more the axis of easy magnetization orients in the plane of the magnetic layer. It is understood that the diffraction intensity is higher and there are more magnetic particles whose axis of easy

magnetization orients in the plane in Example 3 than in Comparative Example 3.

The CoCrPt magnetic layer of the magnetic disk in both Example 3 and Comparative Example 3 does not give diffraction due to the (11.0) plane. This suggests that the crystal grains in the magnetic layer has the uni-crystalline-structure.

Experiments with the orientation control layer in which Au was replaced with Al, Cu, Rh, Pd, Ag, Ir, or Pt, or an alloy thereof gave the same result as mentioned above.

In this example, the orientation control layer must cause the Cr underlayer formed thereon to have (211) orientation. To this end, it is necessary that the (110) oriented orientation control layer as shown in Fig. 15. When the orientation control layer has (110) orientation, the lattice spacing in the two-dimensional lattice approximately agrees with that of the (211) oriented Cr underlayer. Thus, the Cr underlayer epitaxially grows in the (211) orientation and the magnetic layer also epitaxially grows in the (10.0) orientation. The resulting magnetic layer is composed of crystal grains of uni-crystalline-structure and hence the magnetic recording medium has good resistance to thermal fluctuation.

The orientation control layer should have a composition which contains at least one element selected from Al, Cu, Rh, Pd, Ag, Ir, Pt, and Au in an amount not less than 70 at.%. All of these ele-

ments have the fcc structure in the form of simple substance. Their alloys usually form homogeneous solid solution, but they still substantially have the fcc structure. For reference, Table 15 shows the size of the two-dimensional lattice in the longitudinal direction (a) and the lateral direction ($\sqrt{2}a/2$), where a denotes the length of the side of the cube. It is noted that all the elements have the value close to the lattice spacing of the two-dimensional lattice of the underlayer. In the case where any other element than listed above is added, its content should be not more than 30 at.% so that it does not disturb the crystal structure. Such an additional element improves the lattice matching with the Cr underlayer or Cr alloy underlayer or makes fine the crystal grains. According to the present invention, the underlayer has (211) orientation by epitaxial growth thanks to the fact that both the (110) plane of the orientation control layer and the Cr underlayer or Cr alloy underlayer formed thereon have the two-dimensional lattice with an almost equal lattice spacing. Therefore, so long as the orientation control layer substantially has the fcc structure, the effect of the present invention is produced, and hence it is permissible to add any other element (in an amount not more tan 30 at.%) than Al, Cu, Rh, Pd, Ag, Ir, Pt, and Au.

The foregoing description illustrates the case in which the Cr underlayer or Cr alloy underlayer is interposed between the

orientation control layer of fcc structure and the magnetic layer. However, it is also possible to form the magnetic layer directly on the orientation control layer of fcc structure because both the orientation control layer and the (10.0) plane of the magnetic layer have the two-dimensional lattice with an almost equal lattice spacing, as shown in Fig. 15. However, this construction would result in a decrease in coercive force and an increase in media noise as compared with the construction with the Cr underlayer, because the axis of easy magnetization in the magnetic layer has a slightly weak tendency toward in-plane orientation.

For the magnetic recording medium to have a high coercive force and a low noise level, it is common practice to incorporate the magnetic layer with such an element as Pt, Ta, Ti, and Nb. Incorporation with such an element causes the magnetic layer of hcp structure to have a larger lattice constant and the two-dimension lattice formed by the (10.0) plane of the magnetic layer has a larger lattice spacing. (The lattice constant of Co is shown in Fig. 2.) The result is poor lattice matching between the magnetic layer and the orientation control layer of fcc structure and poor lattice matching between the magnetic layer and the Cr underlayer. Therefore, the underlayer should be made of an alloy having a large lattice constant. Such an alloy is exemplified by those of Cr-Ti (5-50 at.%), Cr-Mo (5-100 at.%), and Cr-Mo-Ti. The underlayer made

of any of these alloys improves the in-plane orientation of the axis of easy orientation of the magnetic layer. It is important that the underlayer have the bcc crystal structure. The Cr-Mo alloy used for the alloy underlayer is a homogeneous solid solution as indicated by its phase diagram for bulk metal and hence it has always the bcc crystal structure. This property makes it easy to produce crystals having any desired lattice spacing. The Cr-Ti alloy gives an underlayer consisting of fine crystal grains and hence the magnetic layer formed thereon also consists of fine crystal grains. This is desirable for noise reduction. However, the Cr-Ti alloy for the underlayer should contain a limited amount of Ti not exceeding 50 at.% because Ti has the hcp crystal structure. The underlayer made of Cr-Mo-Ti alloy has the property derived from respective properties of Cr-Mo alloy and Cr-Ti alloy in proportion to the content of each element. The alloy for the underlayer may contain any of Nb, Ta, and W in place of Cr, Mo, and Ti (although the resulting alloy is slightly inferior to the alloy containing Cr, Mo, and Ti). Other elements than mentioned above should not be used because they disturb crystal orientation and give rise to large crystal grains, which leads to a decrease in coercive force and an increase in noise.

According to a preferred embodiment, the underlayer is of double-layer structure, with the first layer containing Cr and the

second layer which is formed on the first underlayer containing at least one element selected from Cr, Nb, Mo, Ta, W, and Ti. This underlayer is desirable because it permits the axis of easy magnetization to assume in-plane orientation in the magnetic layer. The results of the present inventors' experiments indicate the following. If the Cr alloy underlayer is formed directly on the orientation control layer of fcc structure, lattice matching between them is poor and hence the crystal orientation in the underlayer as well as the magnetic layer is poor, because the two-dimensional lattice of the former has a much larger lattice spacing than that of the latter. This problem was solved by replacing the underlayer with that of double-layer structure which consists of a first layer of Cr (adjacent to the orientation control layer of fcc structure) and a second layer which has a larger lattice constant than Cr.

The magnetic disk in this example is combined with the magnetic head shown in Fig. 6 to form the magnetic storage device as shown in Fig. 7. The magnetic head is that of spin valve type provided with a magnetoresistive sensor which utilizes the spin valve effect. Owing to the above-mentioned construction, the magnetic storage device in this example has a recording density exceeding 3 Gbit/in^2. The recording density is three times higher than that of the conventional magnetic storage device. The mag-

netic storage device keeps more than twice the recording density of

the conventional magnetic storage device even when the maximum

likelihood decoder in the recording-reproducing signal processing

unit is replaced with an existing waveform discriminator.

Example 4

This example demonstrates another magnetic disk whose con-

struction and manufacturing process are explained in the following.

As in Example 1 shown in Fig. 3, a glass substrate 30 (65 mm

in outside diameter) was covered with an orientation control layer

31 (and 31') of Ni-50at.% Al-2at.% B (100 nm thick) by DC magnetron

sputtering under the condition that the substrate temperature is

270°C, the Ar gas pressure is 2.0 mTorr, and the input power den-

sity is 0.7 W/cm^2. On the orientation control layer were sequen-

tially formed a first underlayer 32 (and 32') of Cr (20 nm thick),

a second underlayer 33 (and 33') of Cr-30at.% Mo (20 nm thick), a

magnetic layer 34 (and 34') of Co-20at.% Cr-12at.% Pt-1.5at.% Ti

(20 nm thick), and a protective layer 35 (and 35') of C (5 nm

thick) under the same condition as mentioned above. The number

preceding each element represents the content of the relevant

element.

In Comparative Example 4, a magnetic disk was prepared in the

same way as in Example 4 except that the orientation control layer

31 (and 31') of Ni-50at.% Al-2at.% B was replaced by that of Ni-

50at.% Al. The orientation control layer in Example 4 contains B whereas that in Comparative Example 4 does not.

Fig. 16 shows the in-plane magnetic properties and media noise in Example 4 and Comparative Example 4. The value of media noise is that which was measured for signals recorded at 250 kFCI. The value in Example 4 is unity and the value in Comparative Example 4 is relative to unity. It is noted that the magnetic disk in Example 4 is higher in coercive force (H_c) and lower in media noise than that in Comparative Example 4. It is also noted that the magnetic disk in Example 4 is higher in coercivity squareness (S*) than that in Comparative Example 4. This suggests a better resolution.

The CoCrPt magnetic layer was tested for diffraction intensity at the (10.0) plane by X-ray diffraction. The results are shown in Fig. 17. The value in Example 4 is unity and the value in Comparative Example 4 is relative to unity. The larger the value, the more the axis of easy magnetization orients in the plane of the magnetic layer. It is understood that the diffraction intensity is higher and there are more magnetic particles whose axis of easy magnetization orients in the plane in Example 4 than in Comparative Example 4.

The CoCrPt magnetic layer of the magnetic disk in both Example 4 and Comparative Example 4 does not give diffraction due to

the (11.0) plane.   This suggests that the crystal grains in the

magnetic layer has the uni-crystalline-structure.

Experiments with the orientation control layer incorporated

with B in varied content gave the result shown in Fig. 18.   The

abscissa represents the content of B added and the ordinate repre-

sents the media noise in terms of relative values, with the value

for 2 at.% B being unity.   The content at 0.001 at.% on the ab-

scissa represents a null content, because the logarithmic scale

does not have zero.   For the magnetic recording medium to have a

recording density exceeding 3Gbit/in^2, it is necessary to reduce

the media noise below 1.3.   This requirement is met when the con-

tent of B is in the range of 0.05 to 15 at.%.

The same result as above is obtained when the material for

the orientation control layers 31 and 31' is replaced by any of the

following alloys and incorporated with B in an amount of 2 at.%.

Al-50at.% Co, Al-50at.% Fe, Al-50at.% Pd, Co-50at.% Ga, Co-50at.%

Fe, Co-50at.% Ti, Cu-50at.% Pd, Cu-50at.% Zn, Ga-50at.% Ni, Ga-

50at.% Rh, Ru-50at.% Si.

In this example, a mention was made of the magnetic disk in

which the Cr underlayer or Cr alloy underlayer is interposed be-

tween the magnetic layer and the orientation control layer of B2

structure.   However, the construction of the magnetic disk may be

modified such that the magnetic layer is formed directly on the

orientation control layer of B2 structure. This poses no problem in view of the fact that the two-dimensional lattice of the magnetic layer and the two-dimensional lattice of the orientation control layer of B2 structure have almost the same lattice spacing. However, in the case where the Cr underlayer or Cr alloy underlayer is not formed, the axis of easy magnetization has a slightly weak tendency toward in-plane orientation in the magnetic layer. This leads to a decrease in coercive force and an increase in noise level.

For the magnetic recording medium to have a high coercive force and a low noise level, it is common practice to incorporate the magnetic layer with such an element as Pt, Ta, Ti, and Nb. Incorporation with such an element causes the magnetic layer of hcp structure to have a larger lattice constant and the two-dimension lattice formed by the (10.0) plane of the magnetic layer has a larger lattice spacing. The result is poor lattice matching between the magnetic layer and the orientation control layer of B2 structure and poor lattice matching between the magnetic layer and the Cr underlayer. Therefore, the underlayer should be made of an alloy having a large lattice constant. Such an alloy is exemplified by those of Cr-Ti (5-50 at.%), Cr-Mo (5-100 at.%), and Cr-Mo-Ti. The underlayer made of any of these alloys improves the in-plane orientation of the axis of easy orientation of the magnetic

layer. It is important that the underlayer have the bcc crystal structure. The Cr-Mo alloy used for the alloy underlayer is a homogeneous solid solution as indicated by its phase diagram for bulk metal and hence it has always the bcc crystal structure. This property makes it easy to produce crystals having any desired lattice spacing. The Cr-Ti alloy gives an underlayer consisting of fine crystal grains and hence the magnetic layer formed thereon also consists of fine crystal grains. This is desirable for noise reduction. However, the Cr-Ti alloy for the underlayer should contain a limited amount of Ti not exceeding 50 at.% because Ti has the hcp crystal structure. The underlayer made of Cr-Mo-Ti alloy has the property derived from respective properties of Cr-Mo alloy and Cr-Ti alloy in proportion to the content of each element. The alloy for the underlayer may contain any of Nb, Ta, and W in place of Cr, Mo, and Ti (although the resulting alloy is slightly inferior to the alloy containing Cr, Mo, and Ti). Other elements than mentioned above should not be used because they disturb crystal orientation and give rise to large crystal grains, which leads to a decrease in coercive force and an increase in noise.

According to a preferred embodiment, the underlayer is of double-layer structure, with the first layer containing Cr and the second layer which is formed on the first underlayer containing at least one element selected from Cr, Nb, Mo, Ta, W, and Ti. This

underlayer is desirable because it permits the axis of easy mag-

netization to assume in-plane orientation in the magnetic layer.

The results of the present inventors' experiments indicate the

following. If the Cr alloy underlayer is formed directly on the

orientation control layer of B2 structure, lattice matching between

them is poor and hence the crystal orientation in the underlayer as

well as the magnetic layer is poor, because the two-dimensional

lattice of the former has a much larger lattice spacing than that

of the latter. This problem was solved by replacing the underlayer

with that of double-layer structure which consists of a first layer

of Cr (adjacent to the orientation control layer of B2 structure)

and a second layer which has a larger lattice constant than Cr.

The magnetic disk in this example is combined with the mag-

netic head shown in Fig. 6 to form the magnetic storage device as

shown in Fig. 7. The magnetic head is that of spin valve type

provided with a magnetoresistive sensor which utilizes the spin

valve effect. Owing to the above-mentioned construction, the

magnetic storage device in this example has a recording density

exceeding 3 Gbit/in^2. The recording density is three times higher

than that of the conventional magnetic storage device. The mag-

netic storage device keeps more than twice the recording density of

the conventional magnetic storage device even when the maximum

likelihood decoder in the recording-reproducing signal processing

unit is replaced with an existing waveform discriminator.

The present invention materializes a magnetic recording medium which has a high coercive force and a low noise level and is only slightly vulnerable to thermal fluctuation.

This magnetic recording medium is combined with a magnetic head having a reproducing element that utilizes the magnetoresistive effect, so as to provide a magnetic storage device which has a recording density in excess of 3 Gbit/in^2.